National Bureau of Standards

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PRECISION TRANSISTOR OSCILLATOR

As PART of a program devoted to the improvement of measuring and calibrating standards, the National Bureau of Standards has developed a crystal oscillator that is small, portable, dependable, and accurate over long periods of time. The new oscillator unit, developed by Peter G. Sulzer of the NBS staff, utilizes a junction transistor as the source of driving power for a high-stability quartz crystal unit. All components of the circuit, including the power supply, fit into a metal tube less than 2 in. in diameter and about 7 in. long. At an operating frequency of 100 kc, the long-period drift in the first model was about 3 parts in 10^9 per day.

Basic to most work in research, development, and engineering is an accurate reference or standard to which time-intervals and frequencies may be precisely compared. In an attempt to reach a majority of the investigators who need these references, the National Bureau of Standards maintains radio stations WWV (Washington, D. C.) and WWVH (Territory of Hawaii), which transmit standard frequencies (2.5, 5, 10, 15, 20 and 25 Mc) and standard time intervals continuously, night and day. The frequencies that are transmitted are accurate to 2 parts in 10^8, and constant to better than 1 part in 10^9 per day.

To obtain the most precise operation of conventional laboratory-type frequency standards, the signals from WWV or WWVH are used in the calibration procedure. The greatest continuous accuracy is achieved by making the calibration at those times when the received standard frequencies are most efficiently propagated by the ionosphere. But laboratory-type standards of the highest stability are expensive to buy and to operate, and their use has been generally limited to the larger laboratories and research centers. In addition, these standards normally involve such auxiliary equipment as lead-acid batteries, voltage regulators, power supplies, a multiplicity of components, complex temperature controls, and also require large floor space and highly trained operating personnel. The use of transistors in oscillators, counters, amplifiers, etc., shows great promise of making a high-precision frequency standard and crystal clock available when needed. With the development of the transistor oscillator, that part of a compact, high-precision crystal clock is now a reality.

The major components of the NBS transistor oscillator are a type-2517 junction transistor, a high-precision 100 kc GT-cut quartz crystal unit, and a long-life mercury cell. The dry cell supplies power to the whole unit (1.35 volts at 100 μa), and has an active life, under these conditions, of 5 or more years.

Two of the requirements that must be met in developing a high-stability crystal oscillator are constancy of phase shift in the feedback loop associated with the crystal and constancy of the amplitude of oscillation. A constant phase shift is obtained by using large, stable "swamping" capacitors at both crystal connections and by using highly stable components in the remainder of the circuit. Excellent amplitude stability is achieved by operating the transistor in such a manner that collector-voltage limiting is produced.

The transistor is used in the NBS oscillator in the grounded-emitter connection. It produces an output of 0.8 volt across a tuned circuit connected to the collector electrode. The tank circuit, composed of a 350 $\mu\mu$f capacitor and a 6 mh coil, is designed to oscillate at 100 kc; however, the magnitude of the voltage is

too high to be applied directly to the crystal unit. Consequently, the voltage is reduced by means of an attenuator, which consists of a 40 $\mu\mu$f and a 0.01 μf capacitor in series from the collector electrode to ground. The driving current (less than 100 μa) for the crystal is taken from the junction between these capacitors. The crystal voltage is coupled to the output through a 100 $\mu\mu$f capacitor.

Over half of the space in the $1\frac{3}{4}$-in. diameter by 7-in. metal tube is consumed by the crystal, which is mounted in an evacuated glass envelope. The transistor, coil, capacitors, and resistors are supported on a bakelite frame that may be "potted" in casting resin to add to the rigidity of the section. The mercury cell, only about one-half inch deep, is at the base of the assembly and is insulated from the metal "can" by a bakelite shield.

Determinations of the frequency stability with changes in temperature and supply voltage have indicated that the frequency varies approximately 1 part in 10^8 per degree C, and 1 part in 10^8 per 0.10 volt. The transistor oscillator was also compared with the standard oscillators controlling the transmissions of

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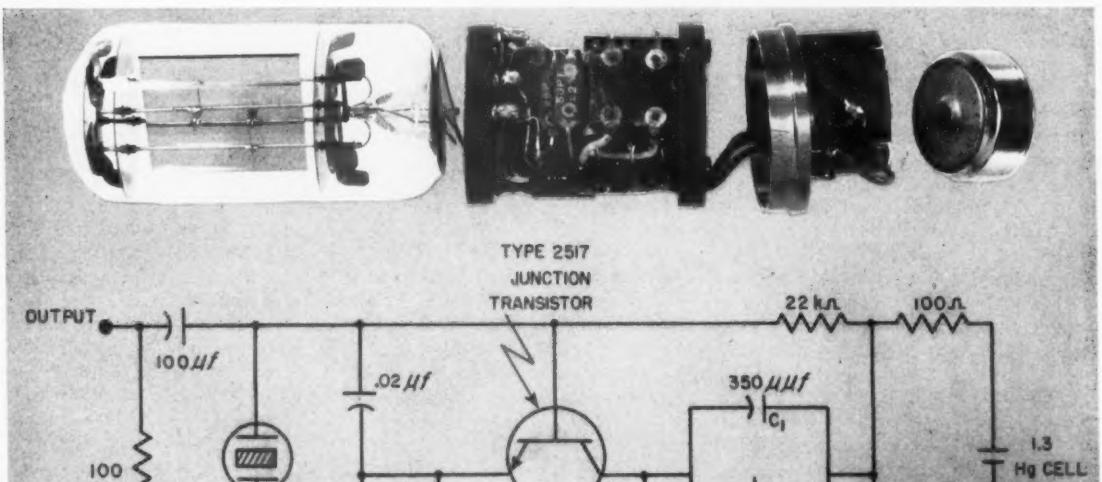
Contents

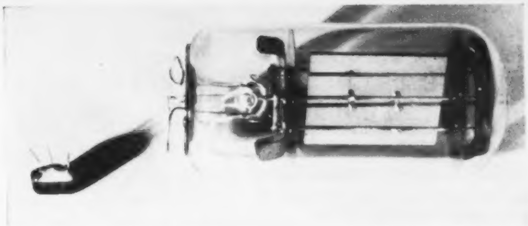
Exploded view and circuit diagram of transistor oscillator developed by NBS. This new oscillator fits into a metal tube less than 2 in. in diameter and about 7 in. long. Mercury cell (right), with life of about 5 years, supplies all power to unit—1.35 v. at 100 μa. Circuit components, including transistor, are lumped together on bakelite form (center), which may be "potted" in casting resin for greater rigidity. GT-cut quartz crystal unit is placed in evacuated envelope (left). Schematic diagram shows various resistor, capacitor, and inductive components of transistor oscillator.



WWV. Short time variations were about ± 3 parts in 10^{10} and the long interval drift—in days—indicated changes of about 3 parts in 10^9 per 24 hours. These figures are comparable to those obtained from vacuum-tube standard oscillators, particularly at the time of their initial installation. Fortunately, frequency drift in the quartz-crystal unit of a conventional-type standard oscillator normally decreases with age. It should also be noted that because the NBS transistor oscillator has just recently been developed, no data exist in regard to long-time stability in terms of years.

The compactness of the NBS transistor oscillator lends itself to more convenient and portable temperature control measures. Heretofore standard quartz oscillators or quartz clocks have required relatively complex temperature control apparatus (operating at temperatures up to 60° C) and special high-reliability power sources.

Tests were conducted on the new transistor oscillator with the complete unit operating at 0° C. Reasonable temperature stability was achieved by merely placing the oscillator in a Dewar flask containing crushed clear ice. Among the results was an indication that the reduced temperatures were responsible for reducing drift and increasing the Q of the quartz crystal unit. Thus, it now becomes possible to make available a readily portable continuously oscillating frequency standard that may be carried to all parts of the world.



Basic components of new transistor oscillator. Driving power for unit is obtained from a type-2517 junction transistor (left). This power is applied to precise GT-cut quartz crystal unit, enclosed in evacuated glass envelope (right).

For additional information about one of the major components of the NBS transistor oscillator, see High stability quartz crystal unit for frequency standards, *by J. P. Griffin, Bell Lab. Record* **30,** *No. 11 (1952).*

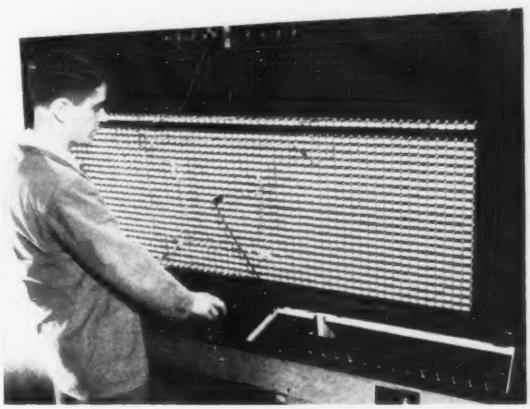
Resistance Network Analog Computer

IN MOST PHENOMENA involving the diffusion of liquids or gases through porous solids, temperature distribution in solids, lamellar flow in fluids, or the field patterns of electrostatic and magnetic fields, the distribution of the equipotential lines is described by the Laplacian equation. Solutions to the equation are obtained either by analytical methods, numerical processes, or analog computers; however, in most practical problems only the latter two systems are feasible. The numerical process is tedious at best, involving extensive mathematical cut-and-try substitutions before a set of solutions results. The analog computer, on the other hand, utilizes the model principle; that is, a problem is set up in terms of another in a less complex field of physics which can be described by the same Laplacian equation.

The most commonly used analog computer for the Laplacian equation is the electrolytic tank, but its accuracy is limited by the nature of its component parts (an electrolyte, sheet metal electrodes, and insulated probes) and the surface tension and polarization of the conducting solution. These limitations are bypassed if the continuously conducting medium is replaced by a fine network of resistors. Such a device has been built by NBS specifically for an investigation of electrostatic problems associated with axially symmetrical electron-optical fields; Dr. L. Marton of the Bureau's electron physics laboratory directed the project. The NBS resistance analog computer is patterned after a unit developed by G. Liebman, but the accuracy of the device has been increased by improvements and modifications of the original design.

Analog Solution of the Laplacian

A widely used numerical approach to the solution of the Laplacian equation is the relaxation method developed by Southwell. In this method, a medium is divided into an array of blocks, and it is assumed



NBS resistance analog computer. Computer is composed of sets of networks (front and rear), each 60 resistance units in axial direction (horizontal) and 20 in radial direction (vertical)—in all, 2,700 resistors are used. Problem is set into computer by shorting of resistors corresponding to physical cross section of model. A probe is placed at one of points for which potential is desired, and value of potential is read from 5-place potentiometer. Twenty-five additional voltages are available through series of jacks on border of resistor panel. Part of controls for these voltages are located in compartment to right of operator.

that an impressed potential is uniform within each block. In a method using the electrolytic tank, the electrolyte is a medium of uniform conductivity providing a potential distribution that satisfies the Laplace equation. Thus, if electrodes are constructed of sheet metal, arranged in proper geometry in a tank filled with a conducting solution, and given the proper potentials from an external source, each point in the electrolyte will have the potential of a corresponding point in a given problem. Measurements are made by placing an insulated probe successively at the points of interest and reading the potential with a voltmeter or potentiometer.

Replacing the continuously conducting medium with a fine network of resistors, as is done in the NBS analog computer, is analogous to dividing the problem into blocks of constant potential. If the electrolyte of the electrolytic tank is thought of as being divided into cells bounded by coordinate surfaces, then the nodal points of the resistance network can be considered as being in the middle of these faces. The value of the resistance between neighboring nodal points is analogous to the resistance of the electrolyte between opposite faces. The resistance network is designed to solve problems for which the potential is independent of one of the coordinates in any coordinate system, i. e., rectangular, spherical polar, or cylindrical polar.

In general, the NBS resistance analog computer gives the same solution to a Laplacian equation as would be obtained by applying Southwell's relaxation technique, in which the differential equation is replaced by an equation involving small finite differences. The resistance network has the advantage of giving the answers instantaneously, whereas the relaxation technique requires laborious computation. The accuracy of the network depends primarily on the fineness of the mesh and the manufacturing tolerances of the resistors; the errors in actual measurement of the potential are quite low. The error in measuring the potential, as well as the error due to the finite size of the mesh, is greatest in the regions where the potential difference between adjacent points is greatest. The value of the latter error can be determined and applied as a correction term to the solved Laplacian. The accuracy of the resistance analog can be further improved by expanding the scale of the problem. Thus, if information must be obtained about a particular segment of the problem, the potentials at a boundary surrounding the segment would be measured. These values would become parametric conditions that would be set into the computer at its physical extreme. In effect, the particular segment under investigation would be magnified. The procedure may be repeated until the limit of accuracy of the computer is reached.

Computer Components

The NBS resistance analog computer is composed of two sets of networks, each 60 resistance units in the axial direction and 20 in the radial direction—in all, 2,700 resistors of 0.5 percent accuracy are used. Special terminating strips are installed at the edges and ends of the computer. The top strip gives the effect of five additional rows of resistors so that important fields near the boundaries of the problem may be determined. Because in axially symmetrical systems the resistor values on the Z axis and leading from the axis to the first row must be infinite, the row of nodal points representing the axis is made to correspond to a distance of $\frac{1}{8}$ unit from the axis. The strips at the ends of the Z axis put the edge of the problem on the last column of nodal points so that advantage may be taken of symmetry about the XY plane whenever it exists.

One-half watt wire-wound resistors with 0.5 percent tolerance make up the network. Except in the terminating strips, the values of the resistors are independent of the Z coordinate. The resistors in the axial direction vary as $1/R$ from 16,000 to 100 ohms (R is the distance from the Z axis); those in the radial direction vary as the natural log of R_2/R_1 from 4,160 to 102 ohms.

A signal generator and an audio amplifier supply the input signal to both the network and a 100-ohm potentiometer. Two 1-ohm potential dividers maintain equal potentials on each electrode and on the input to the precision potentiometer. The potentiometer output and the probe voltage for the node under investigation are amplified by a high-gain audio amplifier, and the amplified difference voltage is observed on a 3-inch oscilloscope. In determining the potential of a point in the medium, the probe is placed at the particular node and the potentiometer is adjusted until no deflection is visible on the oscilloscope. The value of the nodal voltage is read to five places on the potentiometer, which has a guaranteed accuracy of one part in 10,000.

The computer may also be used to investigate problems that are physically too large to be handled in the 60-by-20 network. Twenty-five additional voltages are available through a series of jacks on the border of the resistor panel. The voltages are used to simulate the boundary conditions of the expanded problem. Thus, a particular voltage—representing the boundary condition—is applied to the desired point or points in the network until the complete boundary is simulated by the extra voltages.

In case the shape of the problem is a curve that cannot be fitted to the resistance network, the values of the resistances in the neighborhood of the curve must be altered. However, because the resistors are permanently soldered into the network, only corrections involving a decrease in resistance may be made, these by using external shunts. The choice of cylindrical polar coordinates on the NBS computor makes the network exceptionally well suited to electron-optical problems because the equipotentials nearly always appear along rows or columns of nodes. Thus, the necessity for shunting resistors to take account of curved boundaries seldom arises.

Computer Problems

The field distribution between the parallel plates of a capacitor is used to test the performance of the computer. All the nodal points on one edge of the network are given a potential of one volt, and those on the opposite side are held at zero potential. This type of problem is easily solved by conventional analytical methods. In this particular test the measured computer voltages were found to agree with the analytical values to better than 0.02 percent. Agreement between the computer solution and the analytical solution also proves that no seriously defective resistors or solder connections in the axial direction are present to impair the accuracy of the computer.

Thus far, the NBS computer has been applied exclusively to electrostatic problems. For example, in connection with a theoretical investigation of specially constructed magnetrons, the computer was used to determine the following: A map of the fringe effects at the ends of the anode; an accurate determination of the position and shape of a surface of zero potential produced by guard electrodes; and the change in position of this surface of zero potential for any given change of the guard electrode potentials, with the anode potential held constant.

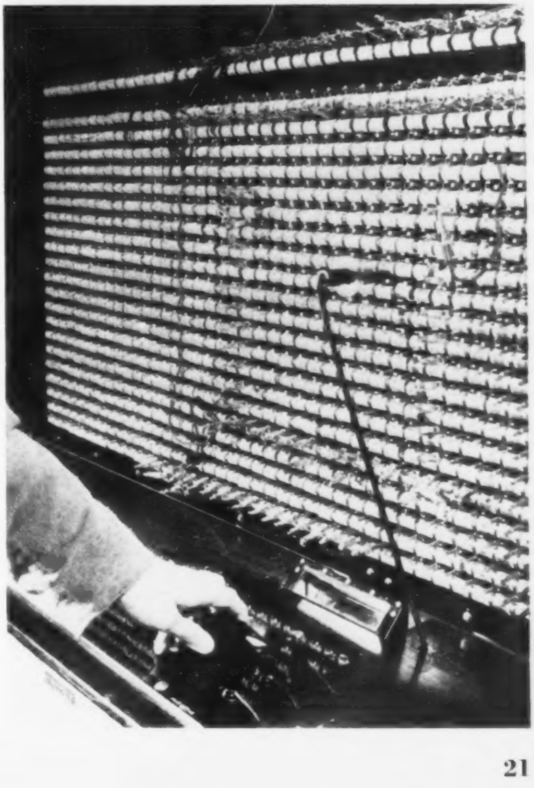
The NBS Analog Computer is especially useful for the solution of design problems. Often a problem arises in which only some criterion of the internal distribution of the fields is known. The boundary conditions that will satisfy this criterion must be determined. For example, one problem may be to find the shape of electrodes that will cause the gradient of an electrostatic field to be zero at a prescribed point in space. Should an electrolytic tank be used, the tank electrodes would have to be removed, reshaped, and realigned every time a change in the boundary conditions became necessary. This subsequently would necessitate conducting the experiment from the very beginning each time such a change occurred. On the other hand, by using the NBS computer, the trial and error process would involve only the changing of the connections to a group of resistors or applying auxiliary voltages where needed. Thus, the solution to a specific problem may be completed in a small fraction of the time required by the electrolytic-tank method.

The adaptability of the computer to other fields is illustrated by a heat flow problem in which the temperature corresponds to the potential of the electrostatic problem. In problems of diffusion the concentration of the diffused matter corresponds to potential. And in lamellar fluid flow the velocity of the fluid is the gradient of a potential that corresponds to the electrostatic potential.

Problems involving boundary conditions offer some limitations to the use of the NBS computer. For example, in the fluid flow problem the boundary of the channel prevents flow normal to it but does not define the "potentials" along its contour. An analog for this type of problem would be produced by cutting out resistors along the boundary line, or where applicable, by arranging the problem so that the boundary line falls on the edge of the network. Because cutting out resistors is impractical and in many problems the edge of the network cannot be used, a "potential" distribution along the boundary must be assumed and set up by means of the auxiliary potentiometers. The potential gradient normal to the boundary is measured at each point, and the boundary potential is adjusted to eliminate this gradient. With successive eliminations of this type, a boundary distribution having the desired property of a vanishing normal gradient is approached. This procedure may be compared with the use of guard rings to avoid fringe fields in thermal conductivity measurements.

For a description of the earlier resistance analog computer, see Solution of partial differential equations with a resistance network analog, *by G. Liebman, Brit. J. Applied Phys.* **1**, *92 (April 1950). (Since this date, Dr. Liebman has also improved his original design to obtain higher accuracies.)*

Close-up of section of computer. Resistor configuration on computer is adjusted for determination of potential distribution in chamber used to measure energy losses of electrons scattered by metal films. Upper strip of shorting clips simulates boundary condition at entrance to field, above which electron gun is normally placed. Next line of clips is shield electrode, and shorting clips perpendicular to this strip are decelerating electrodes. Bottom row of shorting clips simulates metal film by which electrons are scattered. The operator is adjusting 5-place potentiometer to potential in field at which probe is placed (center).



Electrical Measurement of Corrosion Rate

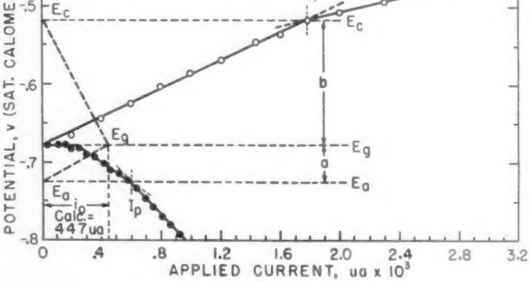
A RECENT laboratory study by NBS proves for the first time that the rate of weight loss of a piece of steel corroding normally in soil can be measured electrically, without actual weighing of the metal. Conducted by W. J. Schwerdtfeger and O. N. McDorman of the Bureau's corrosion laboratory, the study gives further evidence that the electrochemical theory of corrosion applies generally to soils. Although the NBS measurements were restricted to the laboratory, the success of the work suggests the possibility of valuable practical applications, such as determination of the corrosion rate of a tank or other underground structure without the need for visual inspection.

When iron or steel is exposed to the soil, local differences in electrical potential develop at the surface of the metal, resulting in the formation of numerous small corrosion cells. This means that electric currents flow through the soil from certain areas (anodes) to areas of less negative potential (cathodes), with accompanying discharge of hydrogen ions at the cathodes and loss of metal from the anodes. By Faraday's law, the rate of weight loss from corrosion is proportional to the current.

The NBS-demonstrated measuring technique is based on a relation established by other investigators, who showed that the current in a corrosion cell can be expressed in terms of the values of anodically and cathodically (positively and negatively) applied direct current, from an external source, that will just reduce the cell current (corrosion current) to zero. The relation is

$$i_0=\frac{I_p I_q}{I_p+I_q}$$

where i_0 is the corrosion current and I_p and I_q are, respectively, the cathodically and anodically applied currents required to reduce the corrosion current to zero. As increments of current are applied, the potential of the cell changes. When the measured potentials



Polarization curves of a steel electrode exposed to a certain soil. Significant changes in slope of curves occur at values of applied current I_p and I_q.

are plotted against the applied currents, a change in the slope of the curves usually marks the points (I_p and I_q) at which the applied currents have reduced the local corrosion current to zero.

The corrosion cells used by previous investigators in confirming the equation experimentally contained separated anodes and cathodes so that I_p and I_q could be directly measured, and the corrosion currents computed therefrom compared with values obtained by direct measurement. However, when a single piece of metal is exposed to a corrosive medium, as in the NBS study, it is obviously impossible to measure these currents directly. Here the corrosion current, made up of innumerable small cell currents, must be determined indirectly, if at all, from changes in slope of the current-potential (polarization) curves. The NBS study demonstrates for the first time that the total corrosion current i_0—and thus the weight loss—of a single piece of metal normally corroding in soils, and presumably in other aqueous media, can be determined by the equation from values of I_p and I_q obtained from the changes in slope of the cathodic and anodic polarization curves.

In establishing the feasibility of the indirect measuring technique, the Bureau investigators exposed weighed steel specimens, differentially aerated, to five corrosive soils for approximately 2 months. The soils ranged in reaction from very acid (pH 2.9) to very alkaline (pH 9.6). Because of the possibility of changes in rates of corrosion during the 2-month period, polarization curves were obtained at intervals throughout the exposure period. At the end of this period the specimens were removed from the soils, cleaned, and reweighed. Actual weight losses were compared with weight losses calculated indirectly by Faraday's law by use of values of corrosion current (i_0) obtained from the equation on the basis of values of I_p and I_q indicated by changes of slope in the polarization curves. The calculated values of weight loss differed on the average from the actual values by approximately 4 percent.

This technique for indirect electrical measurement of corrosion rate appears to have possibilities for extensive application both in the laboratory and in the field. In laboratory determinations of the corrosion rate of certain materials, for instance, the weight loss resulting from corrosion might actually be exceeded by the cleaning error. The electrical method makes possible much more accurate comparisons of the corrodibilities of such materials. For field determination of underground corrosion the electrical method, if it proves practicable in the field as well as in the laboratory, would have several advantages in addition to obviating the need for excavating the underground object. Although in some soils ferrous metals corrode at a constant rate year after year, in other soils corrosion gradually slows down and in time may virtually cease. Actual weighing or inspection of an object that has been

buried for years will indicate how much total corrosion has occurred but will not show how rapidly, if at all, it has been corroding just prior to inspection. The electrical method, on the other hand, measures the present corrosion rate, which is likely to be of greater practical interest than the history of past corrosion. Furthermore, the electrical method does not involve the removal of corrosion products, which often inhibit corrosion.

For further technical details, see Measurement of the corrosion rate of a metal from its polarizing characteristics, *by W. J. Schwerdtfeger and O. N. McDorman, J. Electrochem. Soc.* **99**, *407 (October 1952).*

Steel specimens exposed to soil corrosion for two months in NBS corrosion laboratory. Specimen on left was exposed to acid soil (pH 2.9), that on right to alkaline soil (pH 9.5).

Half Life of Polonium

RECENT CALORIMETRIC experiments at NBS have confirmed the value of the half life of polonium which was obtained in 1949 in the first accurate measurement of this quantity. In the NBS experiments, an improved type of Bunsen ice calorimeter previously developed at the Bureau was used to measure the heats of radioactivity of polonium samples over time intervals comparable with the half life. Values of half life computed from the observed decline in radioactive power were found to agree with the 1949 values within less than one part in a thousand. The investigation was carried out by D. C. Ginnings and Anne F. Ball of the NBS staff and D. T. Vier of the Los Alamos Scientific Laboratory.

Polonium, a radioactive element of atomic weight 84, was discovered in 1898 by Pierre and Marie Curie in the uranium-containing mineral, pitchblende. Because it is a convenient source of alpha particles, polonium has been used to a considerable extent in neutron sources and in various systems for removal of static charges during manufacturing processes. Its half life has been known approximately for some time but was not accurately measured until 1949, when W. H. Beamer and W. E. Easton* of the Los Alamos Scientific Laboratory obtained a value of 138.3 ± 0.1 days by observing a sample for 97 days. While their method was calorimetric, its principle was somewhat different from the NBS technique; they determined the rate of heat-energy emission by the sample by measuring the temperature difference between a container holding the sample and an identical container which was empty. Because the NBS ice calorimeter offered a convenient method for measuring the energy rates involved and might thus be expected to provide an accurate check on previously determined values, the Bureau developed a procedure for applying the ice calorimeter to this problem.

The NBS ice calorimeter measures heat input by weighing mercury. That is, the heat given off by the sample is allowed to melt ice that is in equilibrium with water in a closed system; and the resulting volume decrease is determined from the weight of mercury drawn into the system. Although the NBS ice calorimeter was not originally developed for determination of radioactive power, it has been found well adapted to measurement of the heat evolved by curie or multicurie quantities of alpha- or weak beta-emitting radioactive materials. One important advantage is the very small heat leak—of the order of 0.0002 watt. An additional advantage for experiments conducted over extended periods is the almost automatic operation of the calorimeter, which requires very little attention during the measurements.

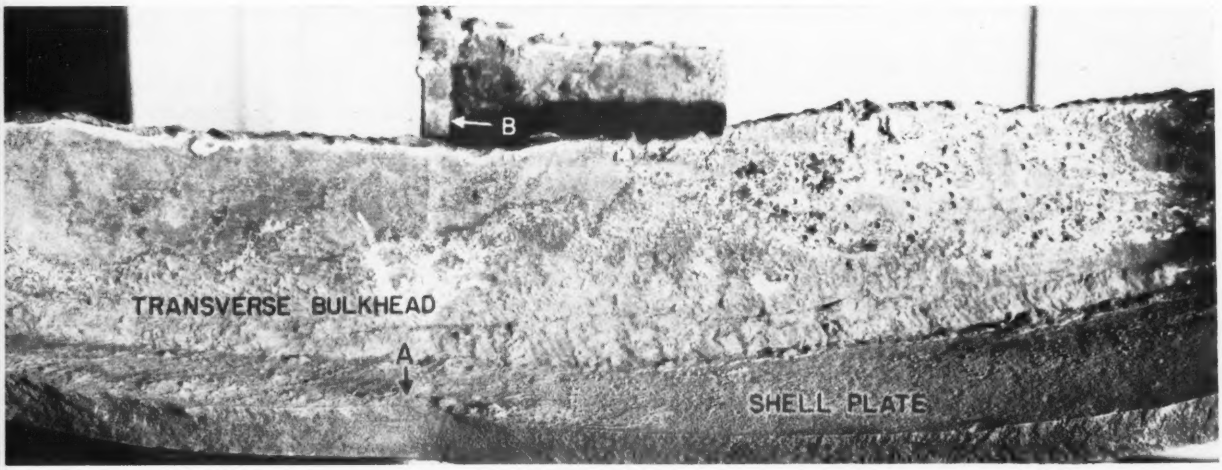
In the NBS investigation, the heats of radioactivity of four samples of polonium, which initially developed power in the range of 0.17 to 1.4 watts, were measured with the ice calorimeter over a period of about seven months. The polonium samples were sealed in glass or metal vessels, which in turn were enclosed in brass outer containers made to fit closely in the calorimeter's central well—a thin-walled tube surrounded by the enclosed ice-water system and an outer ice bath. As the sample gave off heat, the resultant change in the volume of the ice-water system due to melting of the ice was transmitted to a mercury reservoir, resulting in a change in the amount of mercury in a weighed beaker. After a small correction for heat leak, the mass of mercury displaced was converted to an energy value by use of the calibration factor of the calorimeter, previously determined for the instrument by electrical introduction of a known quantity of heat. From the measured duration of the experiment, the energy value was converted into average power. As the rate at which heat energy was produced by the sample was proportional to the number of atoms present, the exponental law of radioactive decay could then be used to determine the half life of the sample. The best value thus obtained was 138.39 days ± 0.1 percent, in close agreement with the value of 138.3 ± 0.1 reported by Beamer and Easton in 1949.

For further technical details, see Calorimetric determination of the half life of polonium, *by D. C. Ginnings, Anne F. Ball, and D. T. Vier, J. Research NBS for Feb. 1953. For information about the improved Bunsen ice calorimeter, see* Heat capacity of sodium between 0° and 900° C, the triple point and heat of fusion, *by Defoe C. Ginnings, Thomas B. Douglas, and Anne F. Ball, J. Research NBS* **45**, *23 (1950) RP2110.*

William H. Beamer and William E. Easton, J. Chem. Phys.* **17, *1298 (1949).*

FAILURES IN WELDED SHIPS

an investigation of the causes of structu



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RESEARCH EFFORTS of the Metallurgy and Mechanics Divisions of the National Bureau of Standards undertaken at the request of the Ship Structure Committee have provided additional evidence on the major causes of structural failures in welded merchant ships—in particular, the critical role of certain properties of steel which, in the past, have not been recognized in specification requirements. Much of this knowledge and pertinent design data obtained at NBS and other laboratories has already been incorporated into ship-construction specifications in an effort to eliminate future failures of this kind. Such failures have cost the nation almost $50 million in the past 9 years, and there have also been costly failures in other structures such as bridges, storage tanks, and pressure vessels. At least 10 tankers and 3 Liberty-type cargo vessels have broken completely in two as a result of the propagation of fractures that originated at some point in the hull structure or its appendages. About 25 other vessels have suffered complete fractures of the strength deck or the bottom plate.

Although fractures have also occurred in riveted ships and structures, these fractures usually ended at the first joint and did not propagate into adjoining plates. A welded structure, however, is continuous, and a crack may propagate across the welds from one plate to the next, resulting in a complete structural failure. Therefore, the problem of fracture origin and propagation has received more attention in the past few years, since welding has largely replaced riveting in the fabrication of ships and many other structures.

In April 1943, the Secretary of the Navy established a Board to Investigate the Design and Methods of Construction of Welded Steel Merchant Vessels. That Board and its successor, the Ship Structure Committee, conducted extensive technical and statistical studies of the casualties, and initiated research projects in several laboratories for the study of some of the factors involved. The Metallurgy Division of the National Bureau of Standards, which had already assisted in investigations of some of the earlier failures, was assigned to the investigation of the plates removed from the fractured ships. To obtain material for the investigation, the Coast Guard made arrangements for samples of fractured plates to be sent to the Bureau.

The NBS metallurgy laboratory has received and examined samples from nearly 100 ships in which fractures have occurred, and tests have been completed on 126 plates selected from 65 of these ships. When sufficient and suitable material was available, the laboratory investigation included examination of the fracture and of welds, microscopic examination, chemical analyses of the plates, Charpy V-notched bar tests over a range of temperatures, and tension tests.

To coordinate the results of the laboratory investigations with service experience, information was ob-

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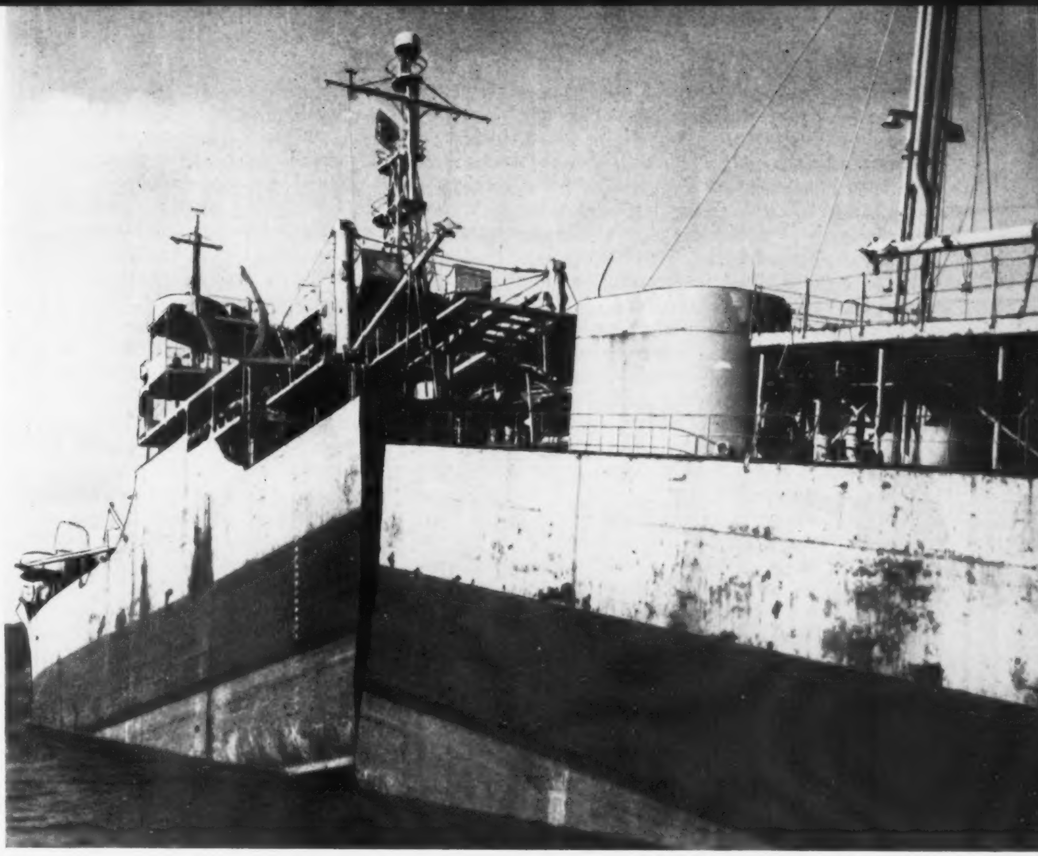


Left: **Fracture edge in shell plating of a tanker. Arrow A shows the fracture source, at the point where the longitudinal ended near the bulkhead. Arrow B indicates the similar longitudinal on the other side of the bulkhead.** ***Right:*** **Tanker that broke in two at dock, viewed from port side, looking forward. The positions of the two parts of the vessel are an indication of the bending load that caused the fracture.**

tained from the Coast Guard and other cooperating agencies regarding the circumstances of the casualties, structural features of the ships involved, location and extent of the fractures, and other pertinent details.

The NBS Mechanics Division became active in the investigation of ship failures in 1947 when tensile tests were begun on a series of large specimens representing some of the hull structural details in which fractures had originated. These tests were designed to determine the relative worth of certain structural details in service. Later, practical improvements of some designs were investigated.

There are three basic factors involved in the prevention of failures of welded structures. First, the material—mostly steel plates and weld metal—should uniformly possess the properties anticipated by the designer, and these properties should not be affected adversely by the efforts of fabricating operations or operating conditions. Second, the design should produce an economically sound structure capable of performing its required functions under all operating conditions. Third, workmanship or fabrication—the work of the fitters, welders, supervisors and inspectors—must carry out the ideas of the designer, and must produce joints of the strength which he intended. The work of the Metallurgy Division has been concerned primarily with the first of these factors, that of the Mechanics Division with the second.

Materials

Tension tests indicated that the plates that had fractured in service would meet the specification requirements under which they were purchased. This type of steel, in the usual tensile test, elongates under load more than 20 percent in 8 inches, and the reduction of cross sectional area is about 50 percent. This indicates that the material is capable of considerable plastic deformation before it will fracture.

The fractures in the ships, however, showed very little evidence of plastic deformation, or ductility. Nearly all of these fractures were of a brittle type, characterized by a break nearly perpendicular to the plate surfaces and a coarse granular or crystalline appearance. The reduction of thickness at the fracture edge was very small, usually less than two or three percent, and the paint or scale on the plate surfaces was not cracked, even very near the fracture. This showed that the fractures had propagated with very little plastic deformation of the steel. Since energy, or the capacity for doing work, is proportional to the integral of stress (or force) times deformation (or distance through which the force acts), it is evident that much less energy was absorbed in the propagation of these fractures than in normal ductile fractures of the material.

The lack of ductility and the brittle nature of these fractures indicated that when the steel was incorpo-

rated in the structure of the ship, the mechanism of fracture, or the mechanical properties of the steel, were not the same as when determined by the usual tensile test using relatively small specimens. This phenomenon is similar to that observed in tests of notched specimens in tension or bending, particularly at low temperatures. The similarity is also evident in the facts that the fractures in the ships occurred more frequently at the lower temperatures, and that the starting points of the fractures could be traced, invariably, to geometrical or metallurgical notches resulting from structural or design details, fabrication processes, or welding defects. This phenomenon, called notch brittleness, is not peculiar to ship plate alone, nor is it confined to metals. The scoring of glass for cutting and the notching of cellophane wrappers are familiar examples in which notch sensitivity is utilized to control the location or direction of a tear or fracture.

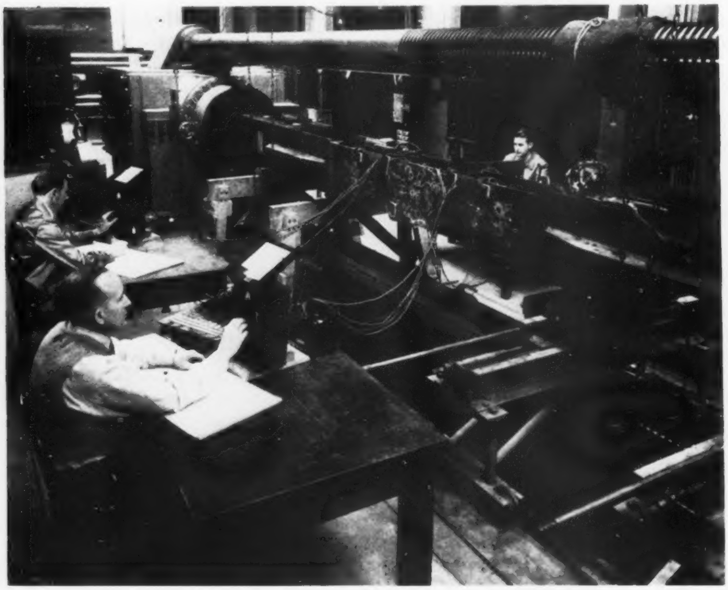
The herringbone markings or chevrons in the fracture were found to be characteristic of the brittle-type fractures in most of the ship plates examined. This type of fracture was observed and reproduced at NBS about 15 years ago, in tests conducted to determine the source of a brittle failure of an aircraft part. These tests showed that a brittle failure may be produced in a normally ductile metal by applying a tensile stress to a notched plate specimen, and also established the fact that the chevrons always point back toward the origin of the fracture. This makes it possible to locate sources of the fractures in the ships.

The source of a number of the fractures that were examined was found to be in the shell plate at the end of a longitudinal stiffener, within a few inches of a transverse bulkhead. The longitudinal, which is welded to the shell plating, is interrupted for a space of about 6 inches to allow for insertion of the transverse bulkhead, to which it is connected, at a point several inches from the shell plating, by gusset plates on the flanges of the longitudinal. This condition, which constituted a structural notch at the abrupt end of the longitudinal stiffener, was responsible for a number of failures in tankers. This design detail is one of those being investigated by the NBS Mechanics Division.

The importance of notch brittleness of the steel as a factor in the failures was recognized early in the investigation, and impact tests, using V-notch Charpy specimens, were included in the examinations of the fractured plates in order to evaluate this factor. In this test the specimen is supported at the ends and broken by the blow of a pendulum on the face opposite the notch. Tests are made at a series of temperatures and the energy absorbed in the fracturing process is measured.

In impact tests of notched specimens, most steels are notch tough at higher temperatures, but as the temperature is lowered they become, suddenly or gradually, more brittle, and the energy required to produce fracture is reduced to a small fraction of that which can be absorbed at higher temperatures. The range of temperatures within which these changes take place, for a given steel, is called the transition range of that steel. Usually, for convenience, a specific point in this range is referred to as the transition temperature, defined by such criteria as the temperature at which the energy absorbed is 50 percent of the maximum, or the temperature at which the energy absorption is at a definite level, say 15 foot pounds for a V-notch Charpy specimen. The transition temperature is one measure of the notch brittleness of the steel.

After impact tests had been completed on only a few plates, it was observed that the plates in which the ship fractures originated showed higher transition tempera-



The Bureau's investigation of welded ship failures involved 126 specimens tested at temperatures which ranged from room temperature to —40° C. *Left:* Taking data during a room temperature test of an interrupted longitudinal specimen. Tensile capacity of this machine: 1,150,000 lb. *Right:* Interrupted longitudinal specimen 10A immediately after fracture. Maximum load sustained: 960,000 lb. *Extreme right:* The frequency distribution of the observed 15 ft-lb transition temperatures of some ship plates.

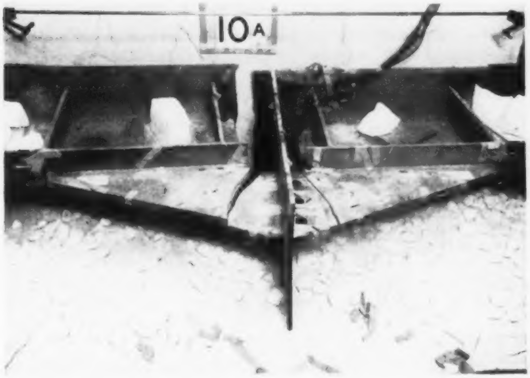
tures than plates that did not contain a fracture source. Therefore, the fractured plates for which definite information was available were clasified into three categories: Those which contained a fracture source (in the ship failures), those which were fractured through, and those which contained the end of a fracture. The plates were also classified in groups on the basis of plate thickness, to permit comparisons of data for similar material, and plates that were not strictly "hull plates of welded ships fractured under normal operating conditions" were placed in a separate miscellaneous group.

Table 1 contains the essential data taken from curves showing the frequency distributions of 15 ft-lb transition temperatures of the plates in the fracture source, fracture through, and fracture end categories. The distribution of the fracture through plates approximated the normal probability curve. The fracture-source plates were found to have a higher average transition temperature, while the relative proportion of fracture-source to fracture-through plates in each interval increased with increasing transition temperature. The latter indicates that the probabiliy of a fracture starting in a plate, under the conditions existing in a structure such as a ship, increases markedly with increasing notch sensitivity of the plate, as determined by the 15 ft-lb transition temperature of V-notch Charpy specimens.

TABLE 1. *Comparison of average transition temperatures of all plates in the source, through, and end categories*

Nature of fracture	Number of plates	Average 15 ft-lb transition temperature	Standard deviation
		°F	°F
Source	30	102.5	25.0
Through	45	65.7	17.5
End	38	56.3	20.1

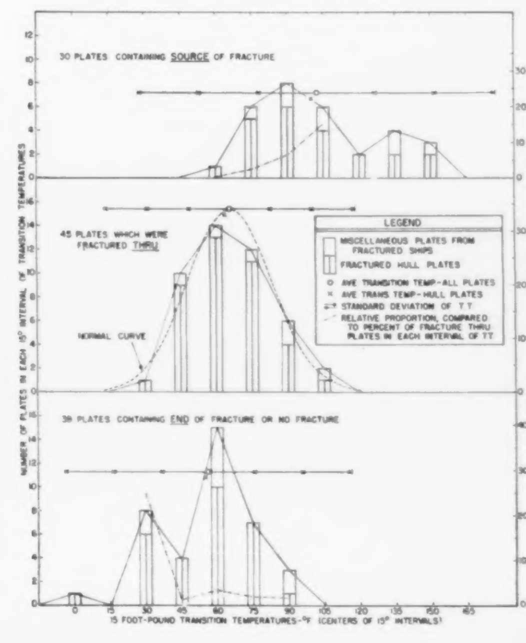
The frequency-distribution curves also showed that the plates with high transition temperatures, in which fractures are most likely to originate, represent the relatively few plates whose notch sensitivity falls in the tail of the probability curve for steels of the quality used when these ships were built. This suggests two possible remedies: (1) Improvement of the average quality of the steel with respect to notch sensitivity. (In effect, moving the entire probability curve in the direction of increased notch toughness, so that a much smaller proportion of the plates in the tail of the curve would fall beyond acceptable limits of notch sensitivity.) (2) Determination of the notch sensitivity of every heat of steel by inspection tests, and rejection of all heats that fail to meet suitable prescribed standards. (In effect, "cutting off the tail" of the probability curve.)

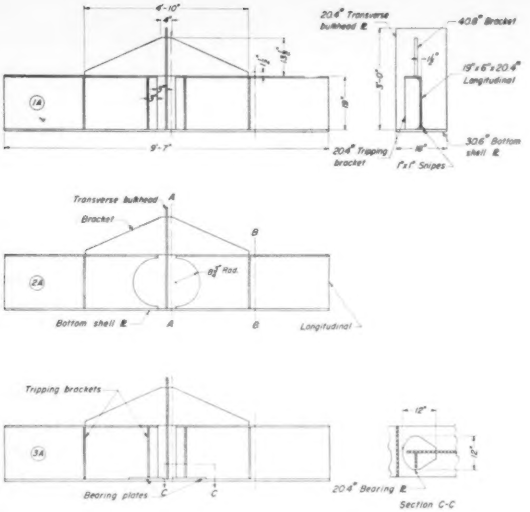


In order to provide information pertinent to (1) above, the test results have been compared with the chemical composition of the steels and an extensive statistical analysis made to determine the effects of individual elements. This analysis has showed that the notch sensitivity is increased with increasing amounts of carbon and phosphorus, and decreased with finer grain size and with increasing amounts of silicon and manganese, within the range of the chemical compositions of the ship plates studied.

Structural Details

A welded tanker afloat at sea may be considered as a hollow beam of great depth upon which a system of complex and variable forces operate. The weight and proportions of the ship, the type and distribution of the cargo, the type of propulsion, and practical fabrication procedures are variables subject to control. The uncontrollable forces of sea and wind can presently only be estimated. The designer's problem is further complicated by the fact that the steel of which a welded ship is made has pronounced changes in mechanical properties within the range of operating temperatures.





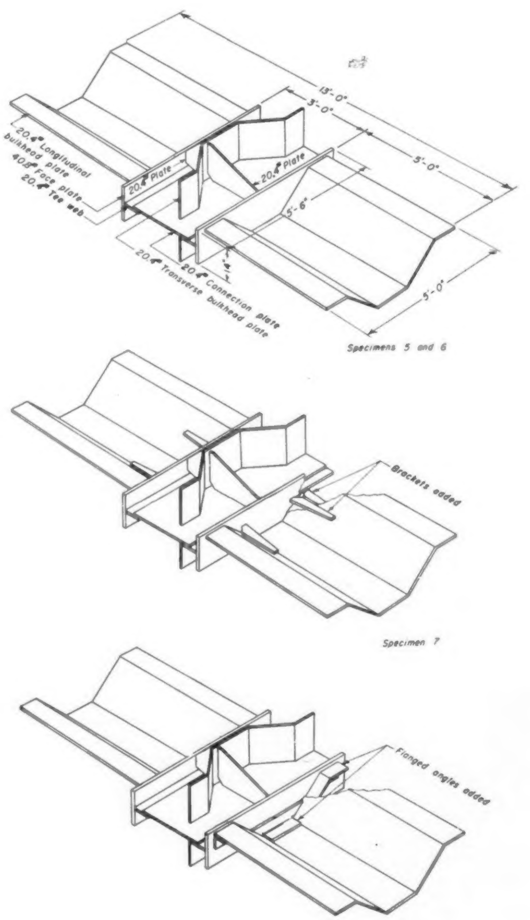
Details of interrupted longitudinal specimens. Specimen 1A is the original basic design. In specimen 2A, material is removed to make a less rigid design. In specimen 3A, material is added to reduce stress concentrations.

Practical solutions of the problems of designing and constructing a steel ship result in various and numerous structural discontinuities, especially at the connections of intersecting members and plates. Such discontinuities often constitute a "mechanical notch" and nearly always produce some concentration of stress in the area of the discontinuity. Since the load-carrying capacity of the structure or ship as a whole, and its ability to absorb energy of deformation, may be seriously reduced by excessive stress concentration, the design details at discontinuities are especially important.

The T2 all-welded tanker was designed and developed during World War II to take advantage of ship-plate steel procurable in large quantities and to minimize time-consuming fitting and joining processes. A large number of these ships were constructed and served their intended purpose. However, to insure and prolong the life of these ships, modification of certain structural details had been made with undetermined results. The prime purpose of the investigation in the Mechanics Division of NBS was to evaluate the load-carrying and energy-absorption ability of certain original structural designs and a few practical modifications of these designs.

Observations on the ships and examinations of fracture sources indicated that fractures occurred in those parts of the ship sustaining large tensile loads. In view of this and the impracticability of simulating exact shipboard loading conditions, tensile tests of the detail in question were made in the laboratory. Specimens were similar to ship construction as far as material, plate thickness, and welding procedures were concerned. Stress studies were made at room temperature; tests in which the applied stresses were below the elastic limit of the material. Since a large number of the fractures occurred in cold water, most of the specimens were tested to failure near 0° F. Some longitudinal specimens were tested at various other temperatures to obtain an indication of the effect of temperature on the mode of fracture.

A source of many of the serious ship casualties was at the intersection of a bottom longitudinal and a transverse bulkhead, a design detail which is repeated more than one hundred times in the structure of a tanker. Three general designs of this detail were investigated by the NBS Mechanics Division. Some results of these tests, grouped by specimen type, are given in table 2. Specimen 1A represents the original design used in T2 tankers and is relatively rigid. The 2A-type



Details of bulkhead intersection specimens. Specimens 5 and 6 are of the original design. Specimen 7 has brackets added to reduce stress concentrations. Specimen 8 has formed angles added to reduce stress concentrations.

TABLE 2. *Results of interrupted longitudinal tests*

Specimen number	Test temperature	Maximum load	Energy to fracture
	Degrees F	*lb*	*ft-lb*
1	0	750,000	30,700
1A	−15	843,000	28,300
1A2	40	1,083,000	[1] 102,900
1A3	20	1,015,000	62,700
1A4	−5	905,000	36,300
1A5	5	1,052,000	94,100
10A	0	960,000	64,300
11A	−5	912,000	36,000
2	0	774,000	46,100
2A	0	993,000	[1] 121,600
2A2	0	918,000	[1] 141,000
2A3	−20	826,000	11,300
3	0	843,000	49,700
3A	10	1,091,000	126,300
12A	−5	1,047,000	[1] 65,900

[1] Broke outside of intersection.

TABLE 3. *Results of bulkhead intersection tests*

Specimen number	Maximum load	Energy to fracture
	lb	*ft-lb*
5	860,000	[1] 11,400
6	774,000	[2] 61,800
7	944,000	[2] 45,200
8	1,129,000	68,800

[1] Partial fracture.
[2] Fracture began in defective weld.

specimen is a more flexible structure due to the removal of material by a semicircular cutout. Specimen 3A retains the rigidity of 1A but reduces the stress concentration in the bottom plate by increasing the plate thickness at the point of highest stress. Minor modifications of these designs were made and tested when they appeared practical.

Four bulkhead intersection specimens of 3 general designs were investigated; results are shown in table 3. Specimens 5 and 6, the original design, were dimensionally similar but varied in welding technique. Specimens 7 and 8 represented two methods used to reduce stress concentrations by adding material to the basic design.

The brittle nature of shipboard fractures was duplicated in the laboratory tensile tests of interrupted longitudinal and bulkhead intersection specimens at low temperature.

Results of NBS tests indicate that the load-carrying ability of the interrupted longitudinal designs does not vary greatly and is probably adequate for the purpose intended. In view of this, the structure which is capable of greater deformation and is therefore able to absorb a relatively large amount of energy before fracture is most suitable for this type service. The design represented by specimen 2A appears somewhat superior in this respect. In some modifications of T2 tankers, designs similar to specimen 2A have been used to replace the original longitudinals represented by specimen 1A. Results of the tests of bulkhead intersection specimens indicate that the addition of material near regions of high stress is beneficial.

NOTE: *The work of the Metallurgy Division was summarized in a paper presented by Dr. M. L. Williams at the Symposium on the Mechanical Properties of Metals at Low Temperatures held at the NBS on May 14 and 15, 1951. The proceedings of this symposium have been published as NBS Circular 520. Results of earlier work done in the Mechanics Division is summarized in: W. R. Campbell,* Stress studies of ship structure specimens, *The Welding Journal, Vol. 30, No. 2, February 1951. W. R. Campbell, L. K. Irwin, and R. C. Duncan,* Stress studies of welded bulkhead intersections, *The Welding Journal, Vol. 31, No. 2, February 1952.*

Fire Resistance of Concrete Floors

Comprehensive data on concrete-floor fire tests made in accordance with the American Society for Testing Materials and the American Standards Association specifications for fire tests have recently been published by NBS. The report is intended to aid building authorities and regulatory groups in evaluating the fire-resistance characteristics of concrete floor constructions and to give designers and builders a basis for the selection of constructions which will meet fire resistance requirements. The increasing use of concrete slab floors in industrial and commercial building and multiple residential dwellings makes adequate fire-resistance ratings of these components desirable. The proper selection of fire-resistant floor material and the closure of vertical openings can restrict fires in large buildings to one floor for a considerable length of time, allowing abatement measures to be taken in the rest of the building.

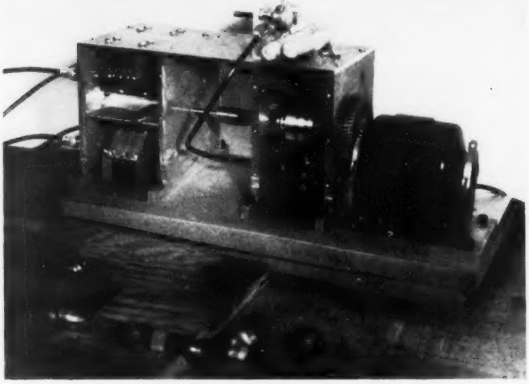
The report covers the results of 11 small-scale and four full-scale fire endurance tests on monolithic concrete floors made with siliceous-gravel aggregates.

Exposed side of floor after fire-endurance test in gas furnace.

Fire Resistance of Concrete Floors, by Daniel S. Goalwin, National Bureau of Standards BMS 134, can be obtained for 15 cents from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Electronic Flowmeter

A New Method for Measuring Fluid Flow

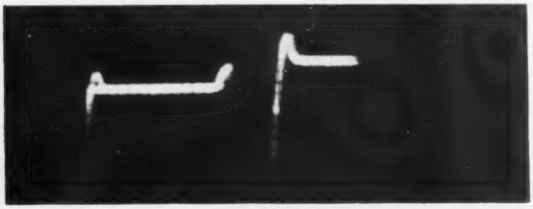


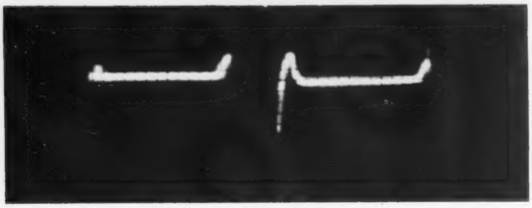
Mechanical switching system used in new electronic flowmeter developed by NBS. Unit periodically switches crystals between transmitting and receiving channels at 10-cycle-per-second rate. Rotor of commutator (left) is made in form of sandwich, consisting of two pieces of insulating material fastened to grounded conductive shield. Compartment (right) contains switching unit for synchronous rectifier.

A NEW TYPE of electronic flowmeter, capable of measuring the air currents in a still room or the rapid flow of fluids in pipes, has recently been developed at NBS. This device, designed by Henry P. Kalmus of the staff of the ordnance electronics research branch, utilizes the change in velocity of sound waves as a measure of fluid flow. It has a very fast response and does not obstruct the fluid currents to make the measurements. In addition, the signal-to-noise ratio is sufficiently high to permit the measurement of extremely small velocities.

Most of the present methods for measuring the velocity of flowing liquids depend on mechanical devices that usually introduce discontinuities in the fluid and have inherent inertia which prevents faithful reproduction of fast velocity changes. One type of flowmeter utilizes the principle of the homopolar machine; but this method cannot be used for gases, and the instrument is, at present, restricted to the measurement of conductive fluids. Another method makes use of the resistance change in hot wires placed in the path of fluid flow. However, besides presenting an obstruction to the flow, the hot wire is not generally applicable to fluids that would change chemically or physically as a result of the heat from the wires.

Oscilloscope patterns for instantaneous flow-velocities obtained with electronic flowmeter.





In the newly developed flowmeter, a sound wave is transmitted over a fixed distance through the flowing fluid, and the phase of the received wave is compared with that of the transmitted wave. The sound energy is imparted to and taken from the fluid through the walls of the containing vessel. No part of the measuring system need come in direct contact with the medium under study. This characteristic of the system makes the unit applicable to the measurement of blood flow in the aorta or for the detection of the flow of chemicals in a closed system, for example, the coolant in a chain reactor. Minor modifications will permit the measurement of the flow of such fluids as gas or oil in a metal pipe or a determination of the relative velocity of a ship to that of the water through which it is moving.

In instances other than those involving extremely high velocities, e. g., in wind tunnels, a simple system utilizing merely a stationary device to transmit energy into the medium and another stationary unit to receive it would be impractical because changes in distance or propagation velocity would produce errors far greater than the variations due to flow. For this reason, the transmitter and receiver of the new flowmeter are exchanged periodically without varying their locations. This is accomplished by use of identical magnetostrictive or piezoelectric exciters, such as barium titanate crystals, as transmitter and receiver and by switching their connections alternately to the receiving and transmitting channels. Thus, the phasemeter displays two phase shifts alternately, one a function of the sound velocity plus the fluid flow and the other a function of the sound velocity minus the fluid flow. The difference between the two phase shifts is a measure of the velocity of the fluid. The switching can be made

to operate faster than the inherent variations occurring in either the transmitter, receiver, or even the medium. Hence, the variations will occur at a minimum of one complete transmitter-receiver switching cycle, and the phase difference will remain unaffected.

In the first experimental model of the NBS flowmeter, a mechanical switching system operating at a 10-cycle-per-second rate is employed. The switching is achieved by a commutator that is inserted between the crystals on one side and a 100-kc oscillator and receiver on the other. The oscillator is connected to an amplifier containing carefully designed limiters that produce a square wave voltage to be injected on one grid of a multigrid phasemeter tube. The receiver amplifier also furnishes a limited signal to the other grid of the phasemeter tube.

The phasemeter tube is by-passed by a capacitor so that fluctuations at the sound-wave frequency are removed and the fluctuations at the switching rate may be applied to a synchronized rectifier. The rectifier is actuated in synchronism with the commutator, but its active period is shorter so that harmful transients occurring during the crystal transition are suppressed.

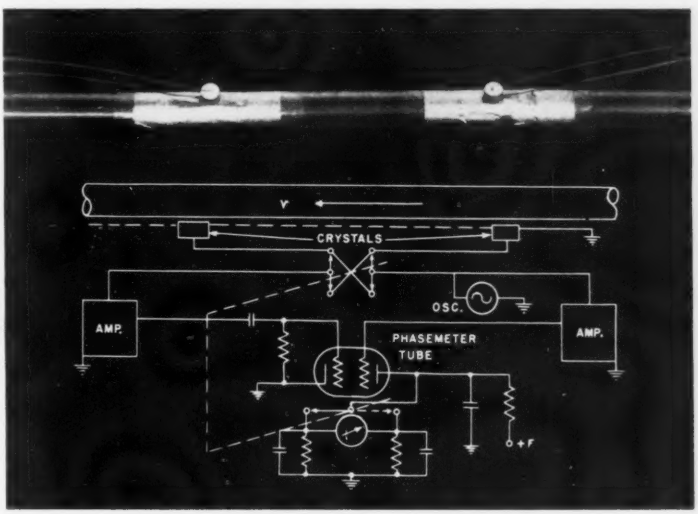
A simple commutator, one that would merely switch the crystals alternately to the receiving and transmitting channels, is unsuitable because of the capacitive cross-coupling between the two channels. In order for the transmitted and received pulses to be absolutely representative of the separation between the crystals and the velocity of the fluid, there must be a minimum of coupling between the two channels. By very careful design of the commutator, the leakage capacitance can be reduced to about 5×10^{-5} $\mu\mu$f, and much of the fringe effects and ground currents is eliminated.

The rotor of the commutator is made in the form of a sandwich, consisting of two pieces of insulating material fastened to a grounded conductive shield. Two conductive segments or sectors are mounted to the insulating material but with no connection to the shield. The shield is brought out to the maximum diameter of the rotor, thereby reducing the fringe effects between the sectors. Four rows of carbon brushes are arranged so that the crystals are connected to either the receiver or oscillator for all positions of the rotor. Capacitive coupling between the sectors is reduced by maintaining a clearance of less than 0.015 inch between the sector shield and the rotor. Similarly, close-fitting shields are provided at the ends of the rotor to assist in reducing fringe effects.

The output of the phasemeter is applied to an electronic high-impedance voltmeter (which can be calibrated directly in terms of velocity) through the rectifier-switch geared to the commutator drive. Fast velocity changes can be observed on the screen of a cathode-ray oscilloscope connected to the plate of the phasemeter tube. Thus, if the plate voltage is made visible, the difference between the voltages developed "upstream" and "downstream" can be used directly to estimate the flow-velocity instantaneously.

A modification to the commutation operation is the use of an electronic switch. By use of vacuum tubes, the switching frequency can be increased to 1,000 cycles, for example, and the time of response can be correspondingly shortened. Four pentode amplifiers are placed between the crystals on one side and the oscillator and receiver on the other. The screen-grid supply is derived from a square-wave generator with a frequency equal to the switching rate (1,000 cps). When the screen voltage is positive, the pentode acts as a normal amplifier; when the potential becomes negative, the electron stream in the tube is blocked and good shielding is provided. The amplifiers are so arranged that one pair operates at a time during each half of the switching cycle.

Further modifications in the flowmeter are being considered; one in particular is concerned with flow in metal pipes. A pulsed and gated phase comparison system will be used for this purpose to eliminate the effects of the direct transmission of the sound through the wall of the pipe.



Crystal arrangement (top) and circuit diagram (bottom) of new electronic flowmeter, which is capable of measuring air currents in a still room or slow or rapid flow of fluid in pipes. Sound waves are transmitted into fluid through walls of container and are received by identical magnetostrictive or piezoelectric exciters, such as barium titanate crystals. Transmitter and receiver of new flowmeter are exchanged periodically by switching system without variation in their locations. Sound energy is amplified and passed on to multigrid phasemeter tube. Output of phasemeter is applied to electronic voltmeter (which can be calibrated directly in terms of velocity) through switch connected to same drive that switches crystals.

Publications of the National Bureau of Standards

Periodicals

Journal of Research of the National Bureau of Standards, volume **50**, number 1, January 1953 (RP2380 to RP2388 incl.). Annual subscription, $5.50.

Technical News Bulletin, volume **37**, number 1, January 1953, 10 cents. Annual subscription, $1.00.

CRPL–D101. Basic Radio Propagation Predictions for April 1953. Three months in advance. Issued January 1953, 10 cents. Annual subscription, $1.00.

Research Papers

Reprints from Journal of Research, volume **49**, *number 6, December 1952*

RP2372. Effect of water on the induction period of the polymerization of methyl methacrylate. I. C. Schoonover, G. M. Brauer, and W. T. Sweeney. 10 cents.

RP2373. Transmittancy of commercial sugar liquors: dependence on concentration of total solids. V. R. Deitz, N. L. Pennington, and H. L. Hoffman, Jr. 10 cents.

RP2374. Extension of the first spectrum of rhodium (RH I). Robert J. Murphy. 10 cents.

RP2375. Heat generation in the setting of magnesium oxychloride cements. Edwin S. Newman, John B. Gilfrich, and Lansing S. Wells. 10 cents.

RP2376. Stiffness of paper. F. T. Carson and Vernon Worthington. 10 cents.

RP2377. A convenient small osmometer. G. A. Hanks and S. G. Weissberg. 5 cents.

RP2378. Low even configurations of the first spectrum of molybdenum (Mo I). Richard E. Trees and Marion M. Harvey. 10 cents.

RP2379. Methods of conjugate gradients for solving linear systems. Magnus R. Hestenes and Eduard Stiefel. 20 cents.

Building Materials and Structures Reports

BMS133. Live loads on floors in buildings. John W. Dunham, Guttorm N. Brekke, and George N. Thompson. 20 cents.

BMS134. Fire resistance of concrete floors. Daniel S. Goalwin. 15 cents.

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